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ABSTRACT

This booklet contains a programmed lesson on oceanic circulation. It is designed to allow students to progress through the subject at their own speed. Since it is written in linear format, it is suggested that students proceed through the program from "frame" to succeeding "frame." Instructions for students on how to use the booklet are included. (JN)

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OCEANIC CIRCULATION

A PROGRAMMED UNIT OF INSTRUCTION

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October, 1984

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OCEANIC CIRCULATION

INSTRUCTIONS

This booklet contains a programmed lesson on the oceanic circulation. It was written in a linear format; that is, you will owrk through the program from "frame" to succeeding "frame". Complete each frame in the program. Use your answer sheet to keep the desired responses (to the left of succeeding frame) covered until you have made your response to a particular frame. As you make the required responses in each frame, check them to be sure they are correct. If you make an error, turn back and review until the point is clarified. If you become confused, or if there is some material which you do not understand, ask the instructor for assistance.

SUGGESTED READING TIME 43 MINUTES

	1. To aid you in understanding the formation and circulation of water types and masses, one important fact must be kept in mind: ALL SEA WATERS RECEIVE THEIR BASIC CHARACTERISTICS WHEN THEY ARE AT THE SURFACE AND IN CONTACT WITH THE ATMOSPHERE. Stated another way, the density characteristics (stability condition based on temperature and salinity) of a particular water type or mass are determined by the characteristics of the _____ in the region where the water type or mass is formed.
atmosphere (air)	2. Oceanic water under a cold air mass experiences continued evaporation resulting in formation of water mass of high salinity. In regions of copious precipitation, water masses will be less saline because they are diluted by the precipitation. The basic characteristics, and changes thereto, of a sea water mass are determined when the water is at the _____ and in contact with the _____ _____ _____.
surface atmosphere	3. Complete the statement below: All sea water masses receive their basic characteristics when _____.
at the surface and in contact with the atmosphere.	4. Using your own words, write a statement that describes where all sea water acquires its basic characteristics. _____ _____ (For answer, see Frame #1.)
	5. The terms "WATER TYPE" and "WATER MASS", mentioned earlier, can now be defined. In regions where the atmospheric conditions are constant, or nearly so, WATER TYPES are formed. A water type is a volume of water having single values of temperature and salinity associated with it. A water type has _____ value for temperature and _____ value for salinity.
one one	6. A volume of water with a single value of temperature and a single value of salinity is termed a water _____.

type

7. There are a few distinct water types that do persist, such as Mediterranean Water and Antarctic Bottom Water, both of which have unique and singular values of temperature and salinity associated with them. Nearly all water types, however, exist for only short periods after they are formed; mixing begins almost immediately. It is this mixing of several water types that produces a WATER MASS.

NO RESPONSE.

---

8. A water mass has a range of temperature and salinity values. The range of values for each is dependent upon the values of the individual water types mixed together to form the water mass. A water mass differs from a water type in that a water mass has a _____ of temperature and salinity values, whereas a water type has _____ value for temperature and _____ value for salinity.

---

range

one

one

9. A large volume of water with a range of temperature and salinity values is a water

_____.

---

10. Match the terms below with their definitions.

_____ Water type

_____ Water mass

a. Has one value for temperature and a wide range of values for salinity.

b. Has a range of values for temperature and salinity.

c. Has a wide temperature range but only one value for salinity.

d. Has one value for temperature and one value for salinity.

---

d Water type

b Water mass

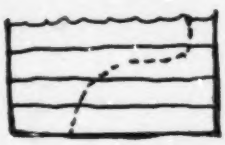
11. There are four important water masses found vertically in the ocean. These masses correspond closely with the different thermal layers. The upper water mass is found closest to the surface and, for the most part, comprises the mixed layer. The intermediate water mass is just below the upper water mass. It has a much larger range of temperature and salinity values than the upper water mass, because its temperature decreases rapidly through the mass. From this, we know that the intermediate water mass corresponds closely with the _____ _____ layer.

main

thermocline

12. The remaining two water masses found vertically in the ocean are the deep water mass and the bottom water mass. These two water masses correspond with the deep layer of the ocean where temperatures are very cold, and the water is quite dense. The bottom water mass is actually a part of the deep water layer and is present in the deeper areas of the ocean.

On the vertical cross section of the ocean below, label the four different water masses. The dashed line represents the temperature characteristics of each layer.



a. _____
b. _____
c. _____
d. _____

---

a. Upper
b. Intermediate
c. Deep
d. Bottom

13. Match the four different water masses in column A below with the thermal layer in column B with which each is generally associated.

A.	B.
____ Upper water	a. Main thermocline layer
____ Intermediate water	b. Deep layer
____ Deep water	c. Mixed layer
____ Bottom water	

__c__ Upper
__a__ Intermediate
__b__ Deep
__b__ Deep

14. In addition to the four water masses found vertically in the ocean, there are three water masses found horizontally with which you must be familiar. The first of these three is the North Atlantic Deep and Bottom Water mass. This water mass is formed in the Labrador Sea, in the region between Iceland and the southern part of Greenland. Surface waters in this area are cooled, and their density increases until the water sinks to become the North Atlantic _____ and _____ Water mass.

---

deep

bottom

15. A major source region for North Atlantic Deep and Bottom Water is the _____ Sea.

Labrador

16. Another water mass which can be identified is the Central Water mass. Central Water is formed in the North and South Atlantic and the North and South Pacific in the areas of the corresponding semi-permanent atmospheric high-pressure areas. Atmospheric conditions in the regions of these high-pressure areas are quite stable, thus allowing central water to form.

    Central Water masses form in the regions of the semi-permanent high-/low-pressure systems.
    (circle one)

---

high

17. The third important water mass is the Antarctic Deep and Bottom Water mass. This water mass is formed in the Antarctic Ocean which completely surrounds the Antarctic Continent. A special area of interest in the formation of this water mass is the Weddell Sea. Here, surface water is cooled to very low temperatures, and ice formation increases salinity. These two factors result in a very dense, heavy water which sinks to the ocean floor as _____ Deep and Bottom Water.

Antarctic

18. An important source region for North Atlantic Deep and Bottom Water is in the _____ Sea; an important source region for Antarctic Deep and Bottom Water is in the _____ Sea.

Labrador

Weddell

19. Match the three important water masses listed in Column A below with their source regions in Column B.

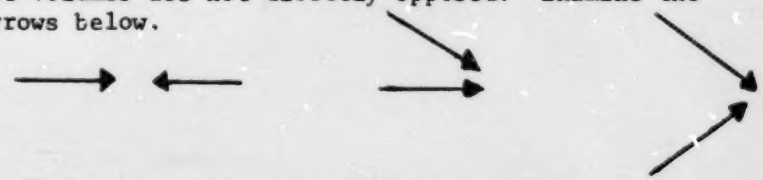
A.	B.
___ North Atlantic Deep and Bottom Water	a. Formed in the Weddell Sea over the continental shelf.
___ Central Water	b. Formed in the Labrador Sea and in the region between Iceland and Greenland.
___ Antarctic Deep and Bottom Water	c. Formed in the Gulf of Mexico and transported into the Atlantic by the Gulf Stream Current.
	d. Formed in the North and South Atlantic and the North and South Pacific in the areas of the corresponding high-pressure areas.

b

d

a

20. In addition to those water masses formed when water sinks as a result of density differentials, there are other water masses formed by mechanical mixing. Tides, currents, and winds all cause water masses to mix, move together, or move apart. CONVERGENCE occurs in regions where two or more water volumes tend to move together. Convergence occurs even though the volumes are not directly opposed. Examine the arrows below.

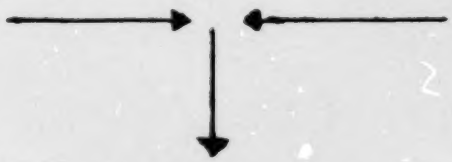


Each of these diagrams indicate a net inflow, and in each case, _____ is occurring.

---

convergence

21. Convergence causes a "piling up" of water and, as a result, sets in motion downward vertical water currents called SINKING. This motion is illustrated below.



In the diagram above:

a. The horizontal arrows illustrate _____

b. The vertical arrow illustrates _____

---

a. convergence

b. sinking

22. In a region where two or more water volumes tend to move together, _____ occurs. This moving together creates downward vertical motion which is termed _____.

---

convergence

sinking

23. When two water volumes tend to move apart, an area of DIVERGENCE is formed. This separation of water requires a volume replacement, which is provided from below. The rising water motion is called UPWELLING and occurs whenever divergence occurs. Examine the diagram below.

In the diagram above:

a. The horizontal arrows illustrate _____

b. The vertical arrow illustrates _____

a. divergence

b. upwelling

24. Match the terms convergence and divergence with the vertical motion with which each is associated.

___ Convergence

____ Divergence

a. Upwelling

b. Convection

c. Sinking

d. Advection

__c__ Convergence

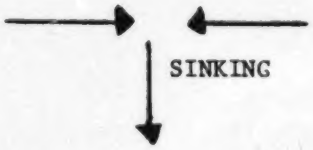
__a__ Divergence

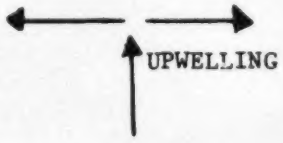
25. In space A below, draw and label a diagram to illustrate surface convergence in the ocean and its resulting vertical water movement; in space B below, draw and label a diagram to illustrate surface divergence and its resulting vertical water movement. In each case, use the correct term when labelling the vertical motion.

A

B

Answer to frame 25





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26. In addition to those localized areas where water masses or currents flow together or apart, there is a distinct circulation pattern in the deep ocean. All oceans show a general circulation patter of deep water flowing toward the equator and surface water flowing toward the poles. This circulation pattern is a factor in transporting heat to high latitudes. Surface water, warmed near the equator, migrates poleward where it gives up its heat to the atmosphere. It then sinks and migrates toward the equator along the ocean bottom.

In general, all oceans show a circulation pattern of deep water flowing _____ and surface water flowing _____.

equatorward

poleward

27. Match the terms deep water and surface water with their respective direction of flow in the general circulation pattern of the oceans.

____ Deep water

____ Surface water

a. Flows poleward

b. Flows equatorward

c. Flows eastward

d. Flows westward

__b__ Deep water

__a__ Surface water

28. Write a statement on the lines below that explains the basic circulation pattern of the deep oceans.

_____

_____

(For answer, see Frame 26)

---

29. Place an "X" beside the statement below that best describes the general circulation pattern of the deep oceans.

_____ a. In general, surface water flows toward the equator, and deep water flows toward the poles.

_____ b. In general, surface water flows from north to south, while deep water flows from south to north.

_____ c. In general, surface water flows poleward, and deep water flows equatorward.

__X__ c.

30. Matthew Fontaine Maury once wrote: "There is a river and an ocean. In the severest droughts, it never fails, and in the mightiest floods, it never overflows. It flows more rapidly than the Mississippi or the Amazon, and its volume is more than a thousand times greater." Maury was refering to the Gulf Stream Current System. Research since his day has proven that he could have safely written: There are numerous rivers in the oceans. These rivers are the many different currents found throughout the world oceans. An ocean current is an organized belt of water in horizontal motion. The primary factor in defining an ocean current is that this belt or band of water in motion, regardless of velocity, must show _____.

organization	31. An organized belt of water in horizontal motion is the definition of an ocean _____.
current	32. An ocean current has not only length and width, but also extends to some depth. An ocean current is an _____ belt of water in horizontal _____.
organized motion	33. On the lines below, write the definition of an ocean current. _____ _____. (For answer, see Frame 30.)
	34. The speed of ocean currents is usually measured in knots and is referred to as current DRIFT. A current moving at 3 knots has a _____ of 3 knots.
drift	35. The direction of an ocean current is the direction toward which it is flowing and is referred to as current SET. A current flowing toward the west _____ westward.
sets	36. If a current off the California coast is flowing from the north at a speed of 2 knots, we can say that this current sets _____ at a _____ of 2 knots.
southward drift	37. Match the terms below with their definitions. ____ Set ____ Drift a. The speed of flow of a current. b. The relative absence of motion beneath the sea surface. c. The speed and direction of current flow. d. The direction toward which a current is flowing

d Set

a Drift

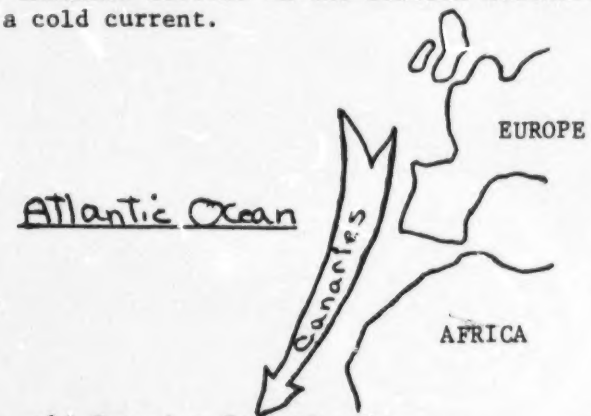
38. Ocean currents are the manifestations of prevailing wind systems; that is, currents generally follow the direction of semipermanent wind systems. Winds about the subtropical high-pressure system over the Atlantic Ocean blow clockwise with a current system that generally flows clockwise. In this system of the North Atlantic Ocean, warm currents set northward along the east coast of the United States, while cold currents set southward along the west coasts of Europe and North Africa. An example of an Atlantic Ocean warm current is the well-known GULF STREAM Current.

The warm Gulf Stream Current System sets

_____.

northward

39. The CANARIES Current in the eastern Atlantic Ocean is a cold current.



The cold Canaries Current sets _____.

southward

40. The Pacific Ocean is very similar to the Atlantic in that the currents also generally flow clockwise, warm currents set northward, and cold currents set southward. The Pacific Ocean counterpart of the Gulf Stream is the JUROSHIO Current. The Kuroshio Current is a warm current that flows off the coast of Japan. Since it is a warm current, we know that it must set _____.

---

northward

41. An example of a Pacific Ocean cold current is the CALIFORNIA Current found off the west coast of the United States. Since the California is a cold current, we know that it must set _____.

---

southward

42. As a result of the change in wind-flow patterns in the Southern Hemisphere, Southern-Hemispheric flow directions are the reverse of Northern-Hemispheric flows. We can generalize, though, by saying that, in both hemispheres, warm currents set _____, and cold currents set _____.

---

poleward

equatorward

43. We can summarize by saying:

a. Surface-current systems generally follow the direction of the semi-permanent _____ systems.

b. As a general rule, at middle and low latitudes, warm currents set _____, and cold currents set _____.

c. In middle and low latitudes, warm currents are usually found near the _____ coast of continents, while cold currents are usually found near the _____ coast of continents.

d. As a result of the Bermuda (North Atlantic) semi-permanent high-pressure cell, the current system of the North Atlantic Ocean flows generally in a _____ direction.

---

a. wind
b. poleward/equatorward
c. east/west
d. clockwise

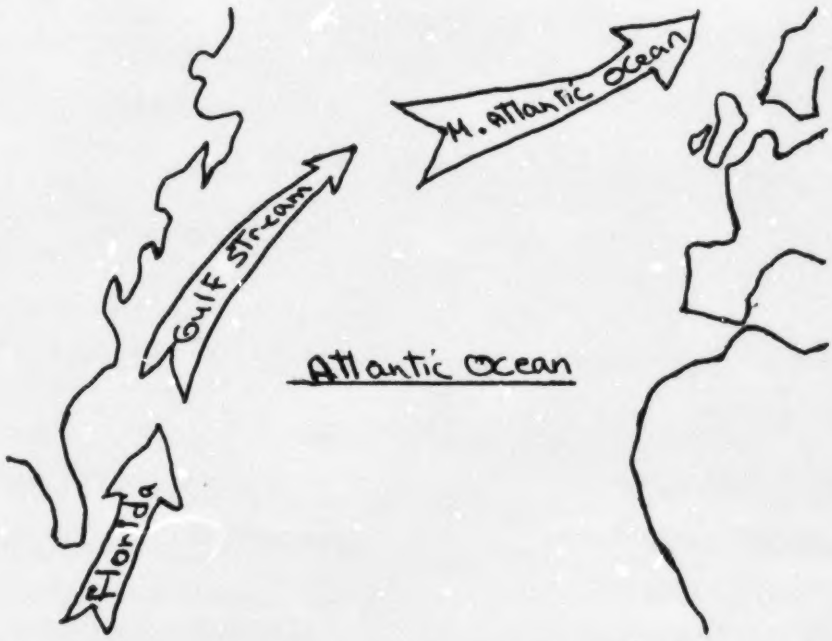
44. There are numerous small-scale deviations from the general circulation pattern; some of the local currents that do not follow the major currents are quite important. These minor currents deviate considerably from the general atmospheric flow patterns and depend upon various oceanic characteristics for their existence. An example of such a current is a tidal current which is set in motion by the interaction of tidal movement and bottom topography.

NO RESPONSE.

	45. One of the major current systems that changes set with seasonal variations is the Indian Ocean System where changing seasonal monsoon winds cause seasonal changes in the set of this current system. During the northeast monsoon, prolonged northeasterly winds over the Indian Ocean cause the current system to set _____.
southwesterly	46. With the coming of the southwest monsoon season, prolonged southwesterly flow causes the current system to set _____.
Northeasterly	47. Seasonal monsoon winds result in variations in the set of the current system in the _____ Ocean.
Indian	48. Place an "X" on the line beside each statement below which contains a true surface-current characteristic. ___ a. Surface-current systems generally follow the direction of the semi-permanent wind systems. ___ b. As a result of the Bermuda high, the current system of the North Atlantic Ocean flows generally counterclockwise. ___ c. As a general rule, at middle and low latitudes, warm currents set toward the pole, and cold currents set toward the equator. ___ d. In middle and low latitudes, warm currents are usually found near the west coast of continents, while cold currents are usually found near the east coast of continents. ___ e. There are numerous minor currents in the oceans that deviate considerably from the general atmospheric flow patterns and depend upon various oceanic characteristics for their existence. ___ f. Variations in the current system in the Indian Ocean are a result of the seasonal monsoon winds.

X a.
____ b.
X c.
____ d.
X e.
X f.

49. There are two major current systems in the Northern Hemisphere with which you should be familiar. These current systems are each composed of several individual ocean currents. In the North Atlantic Ocean, the most important system is the GULF STREAM SYSTEM. This system is made up of three different currents: The Florida Current, the Gulf Stream Current, and the North Atlantic Current. These currents are shown on the diagram below. Examine it carefully.



The three currents in the diagram make up the most important current system in the North Atlantic Ocean. It is the _____ _____ System.

Gulf Stream

50. The other important current system is located in the North Pacific Ocean and is called the KUROSHIO System. This system is composed of two individual currents: The Kuroshio Current and the North Pacific Current. These currents are shown on the diagram below.

The two currents shown in the diagram above make up the most important current system in the North Pacific Ocean. It is the _____ System.

Kuroshio

51. Complete the statements below:

a. The most important current system in the North Atlantic Ocean is the _____ _____ _____ System.

b. The most important current system in the North Pacific Ocean is the _____ System.

a. Gulf Stream

b. Kurushio

OCEANIC CIRCULATION

SELF-TEST

1. On the lines below, write a statement that describes where all sea water acquires its basic characteristics. (Frame 1)

_____

_____

2. Match the terms below with their definitions: (Frame 5)

____ Water type

____ Water mass

a. Has one value for temperature and a wide range of values for salinity.

b. Has a range of values for temperature and salinity.

c. Has a wide temperature range but only one value for salinity.

d. Has one value for temperature and one value for salinity.

3. Match the four different water masses in column A below with the thermal layer in column B with which each is generally associated. (Frame 11)

A	B
___ Upper water	a. Main thermocline layer
___ Intermediate water	b. Deep layer
___ Deep water	c. Mixed layer
___ Bottom water	

4. Match the three important water masses listed in column A below with their source regions in column B.

A	B
___ North Atlantic Deep and Bottom Water	a. Formed in the Weddell Sea area and around the South Pole
___ Central Water	b. Formed in the Labrador Sea and in the extreme North Atlantic.
___ Antarctic Deep and Bottom Water	c. Formed in the North and South Atlantic and the North and South Pacific in the areas of the corresponding high-pressure areas.
	d. Formed only in the central Atlantic Ocean.

5. In space A, draw and label a diagram to illustrate surface convergence in the ocean and its resulting vertical water motion. In space B, draw and label a diagram to illustrate surface divergence and its resulting vertical water motion. In each case, use the correct terms when labeling the vertical motion.

A B

6. Place an "X" beside the statement that best describes the general circulation pattern of the deep oceans.
(Frame 26)

____ a. In general, surface water flows from north to south, while deep water flows from south to north.

____ b. In general, surface water flows poleward, and deep water flows equatorward.

____ c. In general, surface water flows toward the equator, and deep water flows toward the poles.

7. Write Definition ocean current.
(Frame 30)

_____

_____

8. Match the terms at the left with their definitions.
(Frame 34)

____ Set

____ Drift

a. The speed of flow of a current

b. The relative absence of motion beneath the sea surface.

c. The speed and direction of current flow.

d. The direction of flow of a current.

9. Place an "X" on the line beside each true surface-current characteristic statement. (Frame 38)

_____ a. Surface-current systems generally follow the direction of the semipermanent wind systems.

_____ b. As a result of the high, the current system of the North Atlantic Ocean flows generally counterclockwise.

_____ c. As a general rule, at middle and low latitudes, warm currents flow toward the poles, and cold currents flow toward the equator.

_____ d. In middle and low latitudes, warm currents are usually found near the west coast of continents, while cold currents are usually found near the east coast of continents.

_____ e. There are numerous minor currents in the oceans that deviate considerably from the general atmospheric flow patterns and depend upon various oceanic characteristics for their existence.

_____ f. Variations in the current system in the Indian Ocean are a result of the seasonal monsoon winds.

10. Complete the statements. (Frame 49)

a. The most important current system in the North Atlantic Ocean is the

_____ _____ System.

b. The most important current system in the North Pacific Ocean is

the _____ System.

OCEANIC CIRCULATION

ANSWERS TO SELF-TEST

1. All sea water acquires its basic characteristics when at the surface and in contact with the atmosphere.

2. __d__ Water type

   __b__ Water mass

3. __c__ Upper water

   __a__ Intermediate water

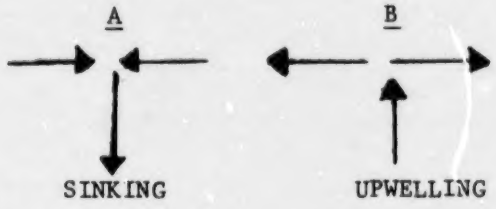
   __b__ Deep water

   __b__ Bottom water

4. __b__ North Atlantic Deep and Bottom water

   __c__ Central water

   __a__ Antarctic Deep and Bottom water

5. 

6. __X__ b.

7. An ocean current is an organized belt of water in horizontal motion.

8. __d__ Set

   __a__ Drift

9. __X__ a.

   __X__ c.

   __X__ e.

   __X__ f.

10. a. Gulf Stream

    b. Kuroshio